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METHOD AND INTAKE CAM FOR RETAINING EXHAUST
RESIDUALS FOR EMISSIONS REDUCTION IN A DIESEL ENGINE

TECHNICAL FIELD

[0001] This invention relates to diesel engines and, more particularly, to a method and intake cam for reducing NO_x in exhaust gas emissions from diesel engines.

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BACKGROUND OF THE INVENTION

[0002] In-cylinder emissions reduction techniques have been extensively explored to meet future regulated exhaust emissions standards for diesel engines. Exhaust gas recirculation (EGR), the most cost-effective way of
10 reducing NO_x levels from spark-ignition engines, is now being considered for use with compression-ignition (diesel) engines. Major constituents of exhaust gas that are recirculated include N₂, CO₂, water vapor, and partially burned hydrocarbons, which affects the combustion process through dilution, thermal, and chemical effects. The dilution effect is caused by the reduction
15 in the concentration of oxygen in intake air; the thermal effect is caused by increasing the specific heat capacity of the charge; and the chemical effect results from the dissociation of CO₂ and water vapor during combustion. In comparison, the dilution effect is the most influencing factor in altering the combustion process.

20 **[0003]** EGR can be achieved either by recirculating some of the exhaust leaving the engine back into the engine (known as external EGR) or by retaining a fraction of exhaust that never leaves the engine (known as internal EGR).

[0004] When compared to external EGR systems, the internal EGR
25 method provides adequate mixing of the EGR fraction with the intake charge and maintains good distribution among all the cylinders, and effective NO_x

reduction without excessively increasing cylinder-specific particulate emissions.

5 **[0005]** In general, internal EGR can be achieved as a result of valve overlap between the intake and exhaust valve opening events. Depending on intake manifold boost level, exhaust gas back pressure, overlap duration and corresponding valve lifts, this fraction can vary substantially. However, during valve overlap, the internal EGR rate at low speed and load can be too high, in particular engines with high thermal load, where the boosted air is also used to cool the cylinders and/or exhaust valves.

10 **[0006]** An alternate to fixed valve timing is variable valve timing. It allows individual adjustment of valve timing as a function of speed and load by applying either an electro-mechanical valve train or an electro-hydraulic valve train. Both systems allow for separate control of intake and exhaust valve timing providing the flexibility to control internal EGR rate. In the
15 case of cam driven valve train having a constant cam lobe profile optimized for certain operating conditions, compromises may result such as increased pumping losses caused by retarded exhaust cam phasing or reduced volumetric efficiency due to early intake valve closure.

20 SUMMARY OF THE INVENTION

[0007] In the present invention, a new cam lobe arrangement for intake valves is provided to achieve internal EGR. The intake cam profile is configured to provide two distinct intake valve events per engine cycle.

25 **[0008]** The first intake valve event precedes the second (main) intake valve event, and has relatively shorter (maximum) lift and duration when compared to main intake valve event. The first intake valve event begins shortly after exhaust valve opening and ends before exhaust valve closing. During a dwell time between the two intake valve events, the intake is kept slightly open with a small lift to prevent seat wear from double intake valve
30 closings.

[0009] By opening the intake valve very early (soon after the exhaust valve opens), the exhaust gases in the cylinder are pushed into the intake manifold as long as the cylinder pressure is higher than the intake manifold pressure. The exhaust that is being pushed into the intake manifold will mix
5 with the fresh air in the intake manifold. When the pressure in the cylinder drops below intake manifold pressure, during the exhaust blow down process, flow reversal occurs. The mixture of fresh air and exhaust gases will first enter into the cylinder followed by fresh air during the engine breathing process. At the end of the gas exchange process, this arrangement
10 effectively traps a part of the exhaust gases (residuals) in the cylinder.

[0010] Optimizing one or more of the following parameters can vary the residual gas fraction that can be trapped inside the cylinder: (a) beginning of the first intake valve opening timing, lift profile, and duration of valve opening, (b) dwell time between the two intake valve events and lift during
15 the dwell, (c) main intake valve opening time, lift profile and duration of valve opening, (d) exhaust valve opening timing, lift profile and duration, and (e) valve overlap duration between the exhaust valve and intake valve.

[0011] In a preferred embodiment, the cam is formed having a base circle with a trapping lobe and a main lobe protruding from the base circle to
20 create the two valve events. A dwell portion connects the trapping lobe and the main lobe and maintains a minimal valve lift between the two intake valve events.

[0012] In another embodiment, a small quantity of fuel is injected late in the combustion cycle such that the cylinder pressure will be relatively higher
25 than the intake manifold pressure during the exhaust blow down process. This helps to increase the back flow of exhaust gases into the intake manifold during the first intake valve event and thereby increase the fraction of exhaust residuals that are trapped in the cylinder. Such a fuel (post) injection event can be implemented on engines fitted with electronically controlled fuel
30 injection equipment (for example, a high pressure common rail injection

system). This arrangement allows further flexibility in trapping the desired fraction of exhaust residual gases in the cylinder when post injection is coupled with double intake valve events as previously described.

5 [0013] In yet another embodiment, exhaust backpressure is modulated such that the residual gas fraction that is trapped in the cylinder can be varied to meet the requirements at different engine operating conditions. For example, engines fitted with variable turbocharger geometry allow changing the dynamic exhaust backpressure at any given engine operating condition.

[0014] These and other features and advantages of the invention will be
10 more fully understood from the following description of certain specific embodiments of the invention taken together with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

15 [0015] FIG. 1 is a transverse cross-sectional view of a turbocharged diesel engine having a cam-actuated valve train;

[0016] FIG. 2 is a cross-sectional view of a camshaft having an intake cam profile according to the present invention; and

[0017] FIG. 3 is a graph showing intake valve lift during exhaust and
20 intake portions of an engine cycle.

DESCRIPTION OF THE PREFERRED EMBODIMENT

[0018] Referring first to FIG. 1 of the drawings in detail, numeral 10
generally indicates, as an example, a four stroke cycle turbocharged and
25 intercooled diesel engine intended primarily for rail locomotive applications. The engine 10 has two cylinder banks 11, each having a plurality of cylinders 12 closed by cylinder heads 13. Pistons 14, reciprocable within the cylinders, define variable volume combustion chambers 16 between the pistons and cylinder heads.

[0019] The cylinder heads 13 contain intake and exhaust ports 17, 18 that communicate with the combustion chambers and are controlled by intake and exhaust valve 20, 21, respectively, mounted in the cylinder heads and biased by the valve springs 22. The valves are mechanically actuated by intake and exhaust cams 23, 24 of a camshaft 25 driving an associated valve actuating mechanism such as intake rocker arm 26. The fuel injection pumps 27 are actuated by the camshaft. The exhaust ports 18 discharge exhaust products through exhaust manifolds 28 to turbocharger 30. These, in turn, draw in inlet charge air and supply it through intake manifolds 31 to the intake ports 17 at pressures varying with engine operating conditions.

[0020] The engine cycle conventionally includes intake, compression, expansion and exhaust strokes of the pistons. Intake charges drawn into the combustion chambers 16 on the intake strokes are compressed with the valves closed. Fuel injected is ignited by the hot compressed gases and the burned gases are expanded, producing power. The combustion products are exhausted providing energy to the turbocharger to boost the pressure of the intake charges. High combustion temperatures in the combustion chambers cause formation of nitrogen oxides (NO_x) which it is desired to control.

[0021] Referring to FIG. 2, an exemplary intake cam 23 is shown having a cam profile according to the invention. The cam profile includes a base circle 32 from which protrude a trapping lobe 34, an angularly spaced intake cam main lobe 36 and a slightly raised dwell portion 37 between the lobes 34, 36. The trapping lobe 34 provides a small intake valve lift during the exhaust phase of the engine cycle. The dwell portion 37 substantially closes the valve during a dwell period toward the end of the exhaust phase but holds the valve slightly off its seat to minimize seat wear. The main lobe 36 provides a large intake valve lift during the intake phase of the engine cycle.

[0022] In an exemplary embodiment of the intake cam 23, the base circle 32 extends for about 180 degrees between the main lobe 36 and the trapping lobe 34. The trapping lobe extends about 40 degrees, the dwell period

extends about 30 degrees and the intake main lobe extends about 110 degrees. A lift curve 38 of the trapping lobe extends outward from one end of the base circle 32 to an apex 40 of the trapping lobe 34, and a closing curve 40 extends from the apex 40 to the beginning of the dwell portion 37.

- 5 The dwell portion extends from the trapping lobe 34 to the beginning of the main lobe 36. The main lobe also includes a lift curve 42, an apex 44 and a closing curve 46 extending to the base circle 32.

[0023] In the exemplary intake cam 23, the height of the main lobe 36 provides approximately 25 mm of associated intake valve lift. However, the
10 valve lift height provided by the main lobe would be varied to suit the application. In addition, the height of the trapping lobe 34 may be varied in a range from 10 to 40 percent of the height of the main lobe. The height of the dwell portion 37 may vary in a range from 1 to 10 percent of the height of the main lobe.

- 15 **[0024]** FIG. 3 is a graph of intake valve lift versus cam angle for the exemplary cam 23 of FIG. 2 wherein the portions of the double lift curve are indicated with the reference numerals of the corresponding portions of the intake cam 23. In this graph, the trapping lobe 34 subtends about 40 degrees, the dwell period 37 about 30 degrees, the main lobe 36 about 110
20 degrees and the base circle subtends about 180 degrees. Vertical lines 48, 50 indicate the points of exhaust valve opening (EVO) and exhaust valve closing (EVC) respectively. A phantom line 52 indicates cylinder pressure during exhaust blowdown and through the intake phase. Horizontal lines 54 and 56 indicate the average intake boost pressure and the average exhaust
25 backpressure, respectively. It should be understood that these values are only exemplary and will be varied to suit the particular conditions of a particular engine embodiment.

[0025] In operation of the embodiment of FIGS. 1-3, the engine 10
operates generally on the four-stroke cycle wherein sequential strokes of the
30 pistons 14 draw in cylinder charges on the intake strokes and compress the

charges on the compression strokes. Fuel is injected near top dead center, is ignited by the hot compressed gases and expanded on the expansion strokes to produce power, and the burned gases are exhausted on the exhaust strokes.

5 **[0026]** In accordance with the invention, the conventional cycle is modified by operation of the dual intake cam 23. Early in the exhaust stroke of each cylinder, the trapping lobe 34 of the intake cam opens the intake valve, or valves, a small amount, allowing some of the pressurized cylinder gases to flow into the intake port 17 and the connected intake manifold 31.

10 As cylinder pressure drops, the intake valve is substantially closed, trapping the exhaust gases in the intake manifold. The dwell portion of the cam holds the intake valve slightly off its seat to prevent increasing valve seat wear by an additional seating of the valve.

[0027] After the dwell, when the cylinder pressure has dropped below
15 the boost pressure of the turbocharged intake manifold, the main intake cam lobe 36 again opens the intake valve, allowing the cylinder to be charged with a mixture of fresh air with the exhaust gases previously retained in the intake manifold. This internal EGR (exhaust gas recirculation) substitutes exhaust products for some of the oxygen and nitrogen containing air in the
20 charge and thereby provides substantial reductions of NO_x emissions in the exhaust products discharged from the engine each cycle.

[0028] In an engine with electronic fuel injection control, a controlled small fuel charge may additionally be injected late in the expansion stroke. This will increase the cylinder pressure and the back flow of exhaust gases to
25 be trapped in the intake manifold, resulting in controlled greater reduction of NO_x where engine conditions may not otherwise provide the necessary dilution of the intake charge.

[0029] The method of NO_x reduction may further be varied by providing for control of engine exhaust backpressure. A variable geometry
30 turbocharger may be used for this purpose, if available, however other

backpressure control devices may alternatively be provided. Modulation of exhaust backpressure could allow closer control of the retained exhaust gases (combustion products) and thus provide a desired degree of NO_x reduction consistent with most efficient operation of the engine.

- 5 **[0030]** While the invention has been described by reference to certain preferred embodiments, it should be understood that numerous changes could be made within the spirit and scope of the inventive concepts described. Accordingly, it is intended that the invention not be limited to the disclosed embodiments, but that it have the full scope permitted by the language of the
- 10 following claims.